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Emerging Waste-to-Energy Technologies: Solid Waste Solution or Dead End?

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Incineration is a dirty word in the United States, at least where trash is involved. We've been burning municipal solid waste (MSW) since the 1880s. But the dawning of the environmental movement eight decades later cast new light on the nitrous oxides, dioxins, and other chemicals emitted from as many as 600 mass-burn incinerators nationwide, which meanwhile had also grown in size.[1,2] The ecological merits of resource conservation and recycling became another area of growing interest.

Now three new approaches to converting trash into energy—so-called waste-to-energy (WTE) technologies—look to leave mass-burn incineration behind by transforming how we think about MSW in the United States. Adherents of these emerging approaches—gasification, plasma gasification, and pyrolysis—promise cleaner emissions and more flexibility in terms of energy output, plus in some cases the virtual elimination of landfilling through a complex two-stage treatment process.[3,4,5,6,7]

But none of the technologies have yet been proven on a commercial scale on U.S. soil using a typical mixed MSW feedstock, says Monica Wilson, program director for the advocacy group Global Alliance for Incinerator Alternatives (GAIA). After years of delays and high-profile failures, the technologies remain stymied by challenges such as operational inexperience, high costs, lack of financing, and concerns about toxic emissions. Furthermore, the heterogeneous nature of MSW can make it a problematic feedstock for power plants, and some critics believe it is more important to assess what materials are actually in MSW and the best uses associated with each of those materials—for instance, recycling, composting, reducing, or redesigning the materials before they enter the waste stream.

Negative public perception of incineration also could prevent acceptance of newer WTE technologies in the United States. Modern mass-burn facilities are a huge improvement over the dirty plants that first drew public outrage. Beginning with the Clean Air Act in 1970, tightened regulations and sophisticated air pollution controls significantly reduced the levels of harmful chemicals emitted by incinerators.

Today, 70 mass-burn plants in 21 states[8] consume about 13% of the nation's trash, down from a peak of 14.5% in 1990.[9,10] Cumulatively they offer roughly 2.5 gigawatts of power in return,[11,12] less than a tenth of what the U.S. solar industry produces.[13] The most recent inventory available from the U.S. Environmental Protection

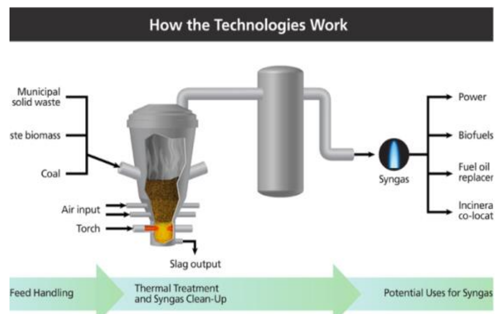
Agency shows that MSW incinerators released about 1% of the quantity of carcinogenic and highly toxic dioxin-like compounds in 2000 that they did just 13 years earlier.[14]

Yet by the 1980s the damage to incineration's reputation was done, as far as many environmental groups and the public at large were concerned. And the battle lines drawn all those years ago remain largely intact today. So claims that these new technologies offer a panacea to waste management and a source of clean, renewable energy have met with skepticism and organized opposition in dozens of communities nationwide faced with proposals in recent years.[15]

Ultimately, if the new technologies are to take hold in this country, developers must find a way to not only support their performance claims, but also demonstrate compatibility with established recycling and composting efforts and achieve financial feasibility in areas experiencing no shortage of landfill space.[16] Even some proponents of the new technologies wonder if that will ever happen.

How Do the Technologies Work?

Those advocates may as well start by getting their facts straight, believes veteran waste-industry consultant and gasification expert Steve Jenkins. Given the technologies' novelty, developers are prone to misrepresent their projects to the public and to regulatory agencies, he says, often leaving them painted with the same brush as mass-burn incinerators.



Jenkins addressed the issue through a recent presentation to industry representatives reiterating the basic differences between gasification and incineration.[17] "My purpose was to beat up on the project developers that have not given these technologies and their projects the good credit that they deserve," Jenkins says. "Too many good projects have died because the public and agency awareness and education were done poorly."

Gasification, plasma gasification, and pyrolysis are closely related and for the purposes of this article are referred to collectively as "conversion technologies" (the term typically encompasses other noncombustion technologies as well). They involve the super-heating of a feedstock—be it MSW, coal, or agricultural residues—in an oxygen-controlled environment to avoid combustion. The primary differences among them relate to heat source, oxygen level, and temperature, from as low as about 600°F (300°C) for pyrolysis to as high as 20,000°F (11,000°C) for plasma gasification.[18]

In these low-oxygen environments the production of dioxins and furans from waste can be significantly reduced compared with incineration,[19,20,21] with emissions potentially falling even below detection limits, Jenkins says. (In one well-publicized exception, a gasification plant in Dumfries, Scotland, repeatedly failed to meet expectations. The plant ultimately closed in 2013 after exceeding emissions limits for dioxins and other pollutants as well as producing far less energy than expected. The Scottish Environment Protection Agency cited "persistent non-compliance with the requirements of the permit" in revoking its license.[22,23])

Conversion technologies are further distinguished from conventional MSW incineration by the production of synthesis gas (or syngas) composed mainly of hydrogen and carbon monoxide, a product of the thermal reactions that take place during the processes. The syngas can then be burned in a boiler system to generate electricity. It can also be processed into fuel for an efficient, low-emissions natural gas generator or refined into other valuable products.[24]

On paper, these differences make conversion technologies cleaner, more efficient, and more valuable than mass-burn incineration. But that doesn't mean the technologies always perform as advertised. "Engineers from the industry side are evaluating the situation from steady state at maximum temperature," says Peter Orris, a professor at the University of Illinois who has tracked WTE technologies from a public health perspective. "I don't have any reason to doubt those estimates are correct, but they're not necessarily real-world." That's because performance is highest and emissions lowest when a facility is running at full steam, he says. Start-up, cool-down, and loading feedstock into the facility's reactors are when many problems occur.

A gap between potential and actual performance is evident at plants currently operating outside the United States, says Umberto Arena, a researcher based in Italy and associate editor of the journal *Waste Management*. This is due primarily to the lack of an affordable solution for syngas cleaning, he believes.

As it stands today, the cleaning of contaminants and impurities from syngas produced via conversion technologies is often cost-prohibitive.[25,26,27] Without an affordable solution for syngas cleaning, which Arena suspects could come in the next five years, most two-stage plants simply burn their syngas in a boiler and then scrub the emissions. This leaves gasification and related technologies only negligibly cleaner than modern mass-burn units and sometimes less efficient.[28]

On top of that, the newer systems must be finely tuned and, in some cases, tend to require a more uniform, pre-sorted feedstock than mass-burn incinerators, Arena says. This can add expense to the operation.

Despite these shortcomings, conversion technologies do have a clear benefit in that they leave behind safer solid residues—and less of it—than burning MSW. Incinerators produce significant amounts of a waste called bottom ash, of which about 40% must be landfilled. The remaining 60% can be further treated to separate metals, which are sold, from inert materials, which are often used as road base. The newer technologies, by contrast, offer immediate recovery of metals and inert slags, with smaller volumes of landfill.[28,29] This explains why conversion technologies have caught on in regions where landfill space is extremely tight or available at a premium.

"If your main interest is to produce electric energy, so far the combustion-based systems are clearly better," Arena says. "If your interest is to strongly reduce the material that is sent to landfill, as in Japan or Denmark or some other areas of Europe, then you could be very interested in gasification."

Landfilling versus Conversion Technologies

Even if the newer conversion technologies have yet to make an unequivocal case that they're better than their mass-burn predecessors, some argue there's another comparison that may be more relevant—and ultimately more convincing.

In the United States today, landfills have a big advantage when it comes to economics. Sending trash to the dump is almost always cheaper than burning it, with tipping fees paid by haulers averaging about 33% less at landfills than at existing incinerators, according to one analysis.[30] That discount would likely be even greater over costly new conversion plants.

But that's not necessarily a deal-breaker in areas with limited landfill space, such as Los Angeles. "Our focus is to develop an alternative to landfills," says Coby Skye, a senior civil engineer for the County of Los Angeles Department of Public Works.[31] The county is running short on landfill space and reluctant to export its trash elsewhere, he says. "We wanted to find something that's more sustainable."

In addition to six operating landfills, Los Angeles County already has two mass-burn incinerators and plans to launch multiple commercial-scale anaerobic digesters, which can produce both energy and compost from wet organic wastes.[32,33] “For over a decade, the county has been encouraging these alternatives to kind of wean ourselves off of the reliance on landfill disposal for residual waste,” Skye says.

A study[34] released in February 2016 by the county Department of Public Works, which Skye helped lead, showed a clear benefit in terms of greenhouse gas emissions for gasification combined with additional recycling and anaerobic digestion, versus the status quo of recycling a portion of MSW and landfilling the rest. The new study compared cumulative greenhouse gas emissions under two different scenarios. The first involved trucking 1,000 tons of post-recycled residuals (i.e., what’s left after current recycling efforts) to a modern dump with a landfill-gas-to-energy system every day for 25 years. This scenario assumed the landfilled residuals would remain there, continuing to break down, for an additional 100 years.

The second scenario involved sending the same 1,000 tons per day of post-recycled residuals to a so-called integrated materials recovery facility. This would include advanced recycling of additional materials followed by processing of residuals via gasification and anaerobic digestion, leaving 136 tons per day for the landfill.

The latter is “what we would call a dream facility,” says Eugene Tseng, an environmental attorney and engineer whose consulting firm helped prepare the report. “You have to have a suite of technologies for what we call the integrated approach. You take the most appropriate technology for the type of waste that’s being generated.”

The study concluded that the landfill scenario would produce a net increase of 1.64 million metric tons of carbon dioxide equivalent emissions over the entire 125 years, while the integrated scenario would result in a net savings of 0.67 million metric tons. This difference of 2.31 million metric tons is comparable to 480,000 fewer passenger vehicles driven for one year. The reduction is achieved in two key ways: 1) through the displacement of emissions from fossil fuel combustion due to the electricity generated; and 2) through increased recycling efforts involved in the extensive pre-processing of materials required before feeding the two plants.[34]

One critical assumption embedded in the study is that biogenic carbon dioxide emissions resulting from the digestion, decomposition, or processing of biologically based materials are considered part of the natural carbon cycle and therefore carbon neutral with zero net greenhouse gas emissions, in accordance with current state, national, and international standards.[35,36,37]

However, a growing community of scientists and others feel it is inappropriate to consider all of these emissions carbon neutral.[38] Environmental organizations have called on the U.S. Environmental Protection Agency to account for carbon emitted from biomass waste on the basis that it too can have an immediate impact on climate change, even if it will theoretically one day be reabsorbed by trees and plants.[39] Such a policy change would mean the landfill scenario in Los Angeles County’s analysis would fare better on greenhouse gas emissions than the state-of-the-art integrated facility.[34]

Philosophical Differences

The deepest divide between ardent critics and defenders of conversion technologies, and the one that evokes the most passion on both sides, doesn’t have to do with dioxins or energy production or carbon accounting, but rather with philosophies about how to handle our society’s trash—and what, in fact, trash really is.

MSW is a mix of all kinds of materials: not just combustible carbon-based materials but also glass, metals, and more. Proponents of a decades-old philosophy called “zero waste” contend that at least 80% of the typical MSW stream can be recycled or composted (e.g., through anaerobic digestion), and that reuse and waste prevention can reduce the remaining portion—if not all the way to zero, then close.

“The primary ecological benefits associated with recycling are in using recovered materials in a production cycle to displace virgin materials,” says Darby Hoover, a solid waste specialist with the Natural Resources Defense Council (NRDC). “The associated savings of energy, water, and carbon associated with that substitution are where most of the environmental benefits occur. … That’s the basis of the ‘closed-loop’ idea. Once you introduce a material into commerce, you should do all you can to keep it there.”

Supporters of conversion technologies, meanwhile, contend that recycling and composting aren’t enough to sufficiently improve landfill-diversion rates, and that some sort of thermal processing of leftovers is necessary. They employ the newer term “zero-waste-to-landfill” to allow for conversion technologies and other WTE strategies as an additional and in some cases preferred form of recycling.

“I strongly feel that the goal of zero-waste-to-landfill cannot be achieved without some additional technologies,” says James Stewart, chairman of the California-based industry group BioEnergy Producers Association. His home state has proposed a plan to improve its recycling rate, stuck at around 50% for the last six years,[40] to 75% by 2020.[41] (By comparison, nationally an average of 34% of MSW is recycled.[9]) This will require recycling roughly 22 million more tons of the current waste stream, which Stewart considers impractical—unless the state’s plan is rewritten so that “recycling” includes the recovery of energy, carbon, metals, and slag through WTE technologies.

While there’s little overlap between these opposing perspectives, in practical terms it may be possible to find middle ground. For instance, some argue that WTE technologies could be used as a stopgap solution to keep high-value materials out of landfills while traditional recycling efforts continue to ramp up.

“I really do have sympathy for folks who are saying, ‘It’s a shame that we’re landfilling this stuff, why can’t we take energy out of it until we can recycle more of it?’” Hoover says. “The problem is that interim solutions can interfere with the higher and better ecological pathway. We want to really make sure we’ve actually maximized recycling and composting before we get to the waste-to-energy facilities.” That said, Hoover believes there might be a role for some types of WTE technologies as a last-ditch effort to extract energy from materials that contain it before they go to a landfill.

Shlomo Dowen, coordinator of the advocacy group United Kingdom Without Incineration Network, believes the traditional conception of zero waste remains within reach—and precludes conversion technologies entirely. “There is very little by way of ‘unrecyclable’ material that could not be addressed by redesign, better source separation, and better sorting technologies,” he says. “And much of what would remain would probably have little or no calorific value so would not be suitable for energy recovery.”

Not Giving Up

Rod Bryden is among those convinced that conversion technologies deserve a place in solid-waste management. The prominent Ottawa businessman runs Plasco Energy Group, a company that hopes to recover power from trash via a proprietary plasma-based technology.

These plans have suffered a number of setbacks, most notably in Plasco’s Canadian hometown early last year.[42,43,44] Plasco had attracted $400 million in investments since its formation in 2005[45] and was considered a leader in the WTE field.[46] But in February 2015, roughly one year after investors asked Bryden to step down as CEO, Ottawa officials terminated the city’s relationship with Plasco due to its inability to secure additional financing needed to construct a long-awaited new plant for full commercial operations. This plant had been contracted to process about 330 tons of post-recycled garbage per day—roughly a third of the city’s household waste. That same day, the company filed for bankruptcy and laid off 80 employees.[47]

But that wasn't the end of it. Seven months after Plasco's collapse, Bryden bought the company from its creditors for a dollar. Now he's back at the helm of a restructured company planning its second act.[48] Bryden says that a failure of leadership, not technology, led to the Ottawa plant's demise, and that Plasco is poised to re-enter the conversion technology industry. "My own view is that Plasco is worth whatever it was created for—$400 million—and has a technology that is ready for commercial delivery," he says.

Instead of using syngas to generate electricity on site for sale to a power company, the company now intends to produce and sell a cleaner fuel-grade syngas for blending with natural gas in third-party power plants. "We were never an expert in the power business, and we're not in that business anymore," Bryden explains.

Tellingly, Plasco's target market is no longer the United States or Canada, but places like the Chinese capital of Beijing, where Bryden says the price of natural gas is roughly three and a half times what it is in New York. If he can find the right location, he hopes to have a new plant under construction by the middle of next year.

Industry consultant Jenkins remains skeptical about the expansion of conversion technologies in the United States. "[In many areas] we've got plenty of land, and nothing is driving the prices of landfills up," he says. "We don't have the economic drivers in the U.S. except in a few cities and counties."

Government subsidies, favorable regulations, and more social acceptance in Japan and parts of Europe have allowed these costly, capital-intensive facilities to advance even as they continue to flounder here. Over the last 40 years Japanese company JFE Engineering has built more than 160 incinerators and 10 gasification plants in its home country, says project development manager Kenny Miyagi.[49] Hoping to expand to the United States, the company opened a branch in Long Beach, California, in 2012. "Ever since then, we have been chasing after opportunities," Miyagi says. "It's a tough market." Without subsidies, incentives, or other public funding, he says conversion technologies appear unlikely to take off here.

Harvey Gershman, another waste industry consultant familiar with the newer technologies, says he's been surprised by their continued failure to gain traction in United States. "For the past ten years I've been saying 'within the next four years.' I was hoping we'd be able to turn the corner on these technologies a lot sooner than we've been able to."

A window of opportunity may already be closing on the technologies, suggests Wilson of GAIA. "There was a flood of proposals, and now there are only a few here and there, and they wither and die on their own. I think the interest overall has really waned over the past year, as people have gotten fed up after hearing so many promises." But, she concedes, "there still are some really strong believers in it."

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References

1. EPA. Energy Recovery from the Combustion of Municipal Solid Waste (MSW) [website]. Washington, DC:U.S. Environmental Protection Agency (updated 22 February 2016). Available: https://www.epa.gov/smm/energy-recovery-combustion-municipal-solid-waste-msw [accessed 20 May 2016].

2. Rootes C, Leonard L, eds. Environmental Movements and Waste Infrastructure. New York, NY:Routledge (2010).

3. Arena U. Process and technological aspects of municipal solid waste gasification. A review. Waste Manage 32(4):625–639 (2012), doi: 10.1016/j.wasman.2011.09.025.

4. Chen D, et al. Pyrolysis technologies for municipal solid waste: a review. Waste Manage 34(12):2466–2486 (2014), doi: 10.1016/j.wasman.2014.08.004.

5. Lombardi L, et al. A review of technologies and performances of thermal treatment systems for energy recovery from waste. Waste Manage 37:26–44 (2015), doi: 10.1016/j.wasman.2014.11.010.

6. GSTC. Technology: Plasma Gasification [website]. Arlington, VA:Gasification & Syngas Technologies Council (2016). Available: http://www.gasification-syngas.org/technology/plasma-gasification/ [accessed 20 May 2016].

7. UCR. Evaluation of Emissions From Thermal Conversion Thermal Conversion Technologies Processing Municipal Solid Waste and Biomass. Riverside, CA:University of California, Riverside (21 June 2009). Available: http://dpw.lacounty.gov/epd/socalconversion/pdfs/UCR_Emissions_Report_62109.pdf [accessed 20 May 2016].

8. Smith K. Navigating waste to energy. Renewable Energy From Waste (15 June 2015). Available: https://www.rewmag.com/article/rew0615-waste-to-energy-facilities-map [accessed 20 May 2016].

9. EPA. Advancing Sustainable Materials Management: Facts and Figures 2013. EPA530-R-15-002 Washington, DC:U.S. Environmental Protection Agency (2015). Available: https://www.epa.gov/smm/advancing-sustainable-materials-management-facts-and-figures-report [accessed 20 May 2016].

10. EPA. Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2012. Washington, DC:U.S. Environmental Protection Agency (February 2014). Available: https://www.epa.gov/sites/production/files/2015-09/documents/2012_msw_fs.pdf [accessed 20 May 2016).

11. ERC. The 2014 ERC Directory of Waste-to-Energy Facilities. Washington, DC:Energy Recovery Council (2014). Available: http://energyrecoverycouncil.org/wp-content/uploads/2016/01/ERC_2014_Directory.pdf [accessed 20 May 2016].

12. Hoagland K. Surveying the US waste-to-energy fleet. Biomass Magazine (1 May 2014). Available: http://biomassmagazine.com/articles/10322/surveying-the-us-waste-to-energy-fleet [accessed 20 May 2016].

13. SEIA. U.S. Solar Market Insight [website]. Washington, DC:Solar Energy Industries Association (updated 9 March 2016). Available: http://www.seia.org/research-resources/us-solar-market-insight [accessed 20 May 2016].

14. EPA. An Inventory of Sources and Environmental Releases of Dioxin-Like Compounds in the U.S. for the years 1987, 1995, and 2000. EPA/600/P-03/002F. Washington, DC:U.S. Environmental Protection Agency (November 2006). Available: https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=159286&CFID=60812463&CFTOKEN=43366043 [accessed 20 May 2016].

15. GAIA. Incinerator Proposals Blocked [website]. Berkeley, CA:Global Alliance for Incinerator Alternatives. Available: http://www.no-burn.org/closed-incinerators-and-proposals-blocked-in-us–canada-2012-2016?preview=1&cache=0 [accessed 20 May 2016].

16. EPA. Municipal Solid Waste Landfills: Economic Impact Analysis for the Proposed New Subpart to the New Source Performance Standards. Research Triangle Park, NC:Office of Air and Radiation, U.S. Environmental Protection Agency. Available: https://www3.epa.gov/ttnecas1/regdata/EIAs/LandfillsNSPSProposalEIA.pdf [accessed 20 May 2016].

17. Jenkins S. Environmental Advantages of Gasification: Public and Agency Awareness [presentation]. Presented at: Gasification Technologies Conference 2015, Colorado Springs, CO, 11–14 October 2015. Available: http://www.gasification-syngas.org/uploads/downloads/2015-presentations/2015-10-3-Jenkins-Environmental.pdf [accessed 20 May 2016].

18. Stringfellow T. An independent engineering evaluation of waste-to-energy technologies. RenewableEnergyWorld.com (13 January 2014). Available: http://www.renewableenergyworld.com/articles/2014/01/an-independent-engineering-evaluation-of-waste-to-energy-technologies.html [accessed 20 May 2016].

19. Zhou H, et al. A review of dioxin-related substances during municipal solid waste incineration. Waste Manage 36:106–118 (2015), doi: 10.1016/j.wasman.2014.11.011.

20. UNEP Chemicals. Standardized toolkit for identification and quantifications of dioxin and furan releases. Geneva, Switzerland:United Nations Environment Programme (2003). Available: http://www.pops.int/documents/guidance/toolkit_2003.pdf [accessed 20 May 2016].

21. Environmental and Safety Services. Incineration and dioxins: review of formation process. Canberra, Australia: Environment Australia (1999). Available: https://www.environment.gov.au/system/files/resources/fec3b9ff-4a26-4b17-9bcb-1ba3c066ca8b/files/incineration-review.pdf [accessed 20 May 2016].

22. McIntyre J. Scotgen (Dumfries) Ltd. Dargavel Energy from Waste Facility. Site Status Report—V12. Dumfries, Scotland, United Kingdom:Scotland Environmental Protection Agency (21 June 2013). Available: http://www.ukwin.org.uk/files/pdf/sepa_dargavel_june_2013.pdf [accessed 20 May 2016].

23. Dumfries energy-from-waste Scotgen plant license revoked. BBC News, UK section, Scotland subsection, online edition (27 August 2013). Available: http://www.bbc.com/news/uk-scotland-south-scotland-23850895 [accessed 20 May 2016].

24. GSTC. Technology: Downstream Conversion Processes [website]. Arlington, VA:Gasification & Syngas Technologies Council (2016). Available: http://www.gasification-syngas.org/technology/downstream-conversion-processes/ [accessed 20 May 2016].

25. Arena U, et al. Advanced aspects of thermal treatment of solid wastes: from a flue gas to a fuel gas technology? Waste Manage 32(4):623–624 (2012), doi: 10.1016/j.wasman.2011.12.022.

26. Milne TA, et al. Biomass Gasifier "Tars": Their Nature, Formation, and Conversion. Golden, CO:National Renewable Energy Laboratory (November 1998). Available: http://www.nrel.gov/docs/fy99osti/25357.pdf [accessed 20 May 2016].

27. GSTC. Technology: Syngas Cleanup [website]. Arlington, VA:Gasification & Syngas Technologies Council. Available: http://www.gasification-syngas.org/technology/syngas-cleanup/ [accessed 20 May 2016].

28. Arena U, et al. A life cycle assessment of environmental performances of two combustion- and gasification-based waste-to-energy technologies. Waste Manage 41:60–74 (2015), doi: 10.1016/j.wasman.2015.03.041.

29. Arena U, Di Gregorio F. Element partitioning in combustion- and gasification-based waste-to-energy units. Waste Manage 33(5):1142–1150 (2013), doi: 10.1016/j.wasman.2013.01.035.

30. Eco-Cycle. Waste-of-energy: why incineration is bad for our economy, environment and community. Boulder, CO:Eco-Cycle (2011). Available: https://www.ecocycle.org/files/pdfs/WTE_wrong_for_environment_economy_community_by_Eco-Cycle.pdf [accessed 20 May 2016].

31. County of Los Angeles. Southern California Conversion Technology [website]. Alhambra, CA:Department of Public Works, County of Los Angeles (2016). Available: http://dpw.lacounty.gov/epd/SoCalConversion/ [accessed 20 May 2016].

32. LACSD. Solid Waste Landfills and Facilities [website]. Whittier, CA:Sanitation Districts of Los Angeles County (2016). Available: http://www.lacsd.org/solidwaste/ [accessed 20 May 2016].

33. County of Los Angeles Department of Public Works. Board Motion of January 27, 2015, Item No. 21-A, Conversion Technology Projects Semi-Annual Status Report: August 2015 Through January 2016. Alhambra, CA:Department of Public Works, County of Los Angeles (9 March 2016) Available: http://dpw.lacounty.gov/epd/SoCalConversion/Documents/SemiAnnual_Reports/2015B.pdf [accessed 20 May 2016].

34. County of Los Angeles. Comparative Greenhouse Gas Emissions Analysis of Alternative Scenarios for Waste Treatment and/or Disposal. Alhambra, CA:Department of Public Works, County of Los Angeles (February 2016). Available: http://dpw.lacounty.gov/epd/socalconversion/pdfs/CT_Comparative_GHG_Analysis_Feb_2016.pdf [accessed 20 May 2016].

35. ARB. California Greenhouse Gas Emission Inventory Program [website]. Sacramento, CA:Air Resources Board, California Environmental Protection Agency (2016). Available: http://www.arb.ca.gov/cc/inventory/inventory.htm [accessed 20 May 2016].

36. EPA. Climate Change > Emissions > CO2 Emissions Associated with Biomass Use at Stationary Sources [website]. Washington, DC:Office of Air and Radiation, U.S. Environmental Protection Agency (updated 11 March 2016). Available: http://www3.epa.gov/climatechange/ghgemissions/biogenic-emissions.html [accessed 20 May 2016].

37. IPCC. Frequently Asked Questions: Task Force on National Greenhouse Gas Inventories (TFI), General Guidance and Other Inventory Issues [website]. Geneva, Switzerland:Intergovernmental Panel on Climate Change (2016). Available: http://www.ipcc-nggip.iges.or.jp/faq/faq.html [accessed 20 May 2016].

38. EPA SAB. SAB Review of EPA's Accounting Framework for Biogenic CO2 Emissions from Stationary Sources (September 2011). EPA-SAB-12-011. Washington, DC:Science Advisory Board, U.S. Environmental Protection Agency (28 September 2012). Available: https://yosemite.epa.gov/sab/sabproduct.nsf/0/57B7A4F1987D7F7385257A87007977F6/%24File/EPA-SAB-12-011-unsigned.pdf [accessed 20 May 2016].

39. Stashwick S. US scientists to EPA: follow the science on biomass to protect our climate & forests [weblog entry]. New York, NY:Natural Resources Defense Council (19 June 2014). Available: https://www.nrdc.org/experts/sasha-stashwick/us-scientists-epa-follow-science-biomass-protect-our-climate-forests [accessed 20 May 2016].

40. CalRecycle. California's Statewide Recycling Rate [website]. Sacramento, CA:California Department of Resources Recycling and Recovery (updated 15 June 2015). Available: http://www.calrecycle.ca.gov/75percent/RecycleRate/default.htm [accessed 20 May 2016].

41. CalRecycle. California's 75 Percent Initiative: Defining the Future [website]. Sacramento, CA:California Department of Resources Recycling and Recovery (updated 15 March 2016). Available: http://www.calrecycle.ca.gov/75percent/ [accessed 20 May 2016].

42. Plasco. Our Technology [website]. Ottawa, Ontario, Canada:Plasco Energy Group, Inc. Available: http://www.plascoenergy.com/our-technology/ [accessed 20 May 2016].

43. Rubin S. Plasco puts trash gasification plant on hold after state declines to redefine renewables. Monterey County Weekly (30 August 2012). Available: http://www.montereycountyweekly.com/news/local_news/plasco-puts-trash-gasification-plant-on-hold-after-state-declines/article_c34d45d4-3780-57b8-8006-bd5100e15fd2.html [accessed 20 May 2016].

44. Chianello J, Pearson M. Ottawa severs ties with Plasco as company files for creditor protection. Ottawa Citizen, News section (10 February 2015). Available: http://ottawacitizen.com/news/local-news/plasco-energy-group-files-for-creditor-protection [accessed 20 May 2016].

45. Plasco. NSPG Update on Plasco CCAA Outcome [press release]. Ottawa, Ontario, Canada:Plasco Energy Group (28 September 2015). Available: http://www.plascoenergy.com/2015/09/nspg-update-on-plasco-ccaa-outcome/ [accessed 20 May 2016].

46. The New Economy. The New Economy Awards 2014: Cleantech [website]. London, United Kingdom:The New Economy Magazine (2016). Available: http://www.theneweconomy.com/awards/2014 [accessed 20 May 2016].

47. CBC News. Plasco obtains creditor protection, 80 jobs terminated. Canadian Broadcasting Corporation, Canada section, Ottawa subsection (10 February 2015). Available: http://www.cbc.ca/news/canada/ottawa/plasco-obtains-creditor-protection-80-jobs-terminated-1.2951751 [accessed 20 May 2016].

48. Pilieci V. Rod Bryden buys back Plasco from creditors for $1. Ottawa Citizen, Business section (28 September 2015). Available: http://ottawacitizen.com/business/local-business/bryden-buys-back-technology-from-failed-plasco [accessed 20 May 2016].

49. JFE. Products > Environment > Waste to Energy Plants [website]. Tokyo, Japan:JFE Engineering Corporation. Available: http://www.jfe-eng.co.jp/en/products/environment/#anc03 [accessed 20 May 2016].